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An Exploratory Investigation of the Cooling Drag Associated with General Aviation Propulsive Systems

NASA Grant Number NSG 1083

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An exploratory effort has been undertaken to systematically investigate the drag associated with the cooling-air flow of contemporary general aviation engine installations. The purpose of this research is to develope a clear specification of cooling drag, provide design data and information, and to develope experimental methods and techniques for determining the value of the cooling drag. It should be noted that this program represents the initial phase of an extensive study of this subject which will be required in order to develope a full understanding of the physical processes involved. The specific objectives of the program are as follows: determine the state-of-the-art which is manifest by available data and design methods, establish appropriate instrumentation and experimental techniques for determining cooling drag by flight test, and determine the relative magnitude and define the significant components of cooling drag.

The flight test vehicle is a Beechcraft T-34, Mentor, on loan from the Department of the Navy. The T-34, although a relatively old design, is representative of contemporary, high-performance, single-engine aircraft. The cooling drag was experimentally determined by two independent methods which provides a cross-check and the opportunity to correlate techniques.

A complete bibliography of source material has been compiled that covers the mid-1920 period to early 1975. Synopses of the available technical papers and reports have been prepared and assembled as a compendium of design information for installation of aircraft piston engines. The state-of-the-art of design factors which are relevant to the general aviation propulsive system installation is not well represented by publications in the open literature. Much of the pertinent data and some of the design methods are proprietary and cannot be obtained for publication. The most highly developed design procedure available in the open literature is the Lycoming installation manual which is essentially an adaptation of design methods developed by Pratt and Whitney circa 1945, and specifications of cooling air requirements peculiar to each of the Lycoming engines. Although this manual is inconclusive, it is a noteworthy addition to the literature and Lycoming is to be commended for their exceptional efforts. A work task has been undertaken to develope a design manual that will include inputs from the engine installation engineers and airframe propulsive system designers. This manual will incorporate current design practice to the extent that company proprietary policies will permit release and publication of data and procedures and will include most of the data generated during this program.

A general purpose instrumentation system has been designed and fabricated for the measurement of pressures and temperatures in and around the engine cowl/nacelle. The system is modularized and portable, and can be moved intact to other test vehicles. It is completely self-contained and does not rely on the host aircraft for power or support. The measurement system is composed of three synchronized 48 channel scannivalves which provides for 144 pressure data-points, 20 thermocouples for the measurement of engine internal cowl temperatures, an airspeed transducer and an altitude transducer. All of the data is synchronized to a crystal controlled clock. This system is shown schematically in Figure 1.

Installation of two flight test booms incorporating total and static pressure probes, and pitch and yaw servos has been completed. Calibration flights have been completed and demonstrated satisfactory performance of each of these. These are self-aligning probes and have virtually no position error from 70 knots through 150 knots. In addition, an outside air temperature probe, a shielded thermister, has been installed on the lower left wing. These probes are the primary source of aircraft performance data, (altitude, airspeed, etc.).

An array of total pressure and static pressure probes and thermocouples has been installed in each of the inlets and augmentor tubes as shown in Figures 2 and 3 respectively. The engine baffle is instrumented similarly to standard Lycoming test cell practice (Figure 4). In addition, total and static pressure probes and thermocouples are located at several positions in the upper and lower cowl to provide flow data throughout the cowl. Surface pressures are being measured at points extending along lines from the inlet lip to the firewall. The cowl is adequately instrumented to allow calculation of all the pertinent characteristics of the internal flow.

The data are recorded on board the aircraft in analog form on a seven channel FM/FM analog tape recorder (Lockheed Model 417). The data recorded are: 3 channels of scannivalve measured pressures, 1 channel of airspeed data, 1 channel of altitude data, 1 channel of multiplexed temperature data, and a channel of master clock data. The master clock data is used to time synchronize the analog to digital converter that is used to convert the recorded data into digital form for storage on digital magnetic tape. The digital magnetic tape interfaces directly with the University mainframe computer, a UNIVAC 1106, which is used for data analysis and manipulation. The data is converted to engineering units and plotted at the computing center. A secondary instrumentation system has been installed on a photo panel to provide a redundant source of aircraft performance data. The panel has a calibrated airspeed indicator, calibrated altimeter, clock, outside air temperature read-out and a binary counter. Data is recorded on a 16 mm film at a rate of 1-frame per second.

The flight test program consists of six schedules which involve calibration of the pitot-static system, calibration of the primary instrumentation system, gliding flight drag polars for three cowl configurations, and cowl performance with engine power. The flight test procedures for developing drag polars consists essentially of a series of saw tooth climbs and power-off glides at constant calibrated airspeed. A drag polar is generated for each of the aircraft test configurations. In addition, cowl internal flow data is accumulated for each flight condition so that momentum changes of the cooling-air flow through the cowl can be compared with changes in total airplane drag indicated by drag polar shifts. All glides are with the engine off and propeller feathered. The propeller was obtained on loan from Hartzell Propeller and the governor and unfeathering accumulator from Woodward Governors. This system provides increased safety and flexibility during the power-off gliding flight tests.

The three cowl configurations are; the standard T-34 arrangement, inlets blocked so there is no internal flow, and the augmentor tubes fixed with butterfly valves in each to throttle the cowl flow. Changes in total airplane drag, changes in the momentum of the internal flow, and changes in the external cowl pressure field are determined as a function of flight condition and air mass flow rate through the cowl. The drag associated with the engine installation and the internal flow of cooling air is determined by comparing the airplane total drag for each cowl configuration to the case of no cooling air flow with the cowl closed. Airplane drag increments due to changes in airframe parasite drag caused by perturbations to the external flow induced by inlet spillage are also attributed to cooling drag.

Table 1 is a compilation of the six flight test schedules which indicates configuration and flight operating conditions. A total of 131 test runs (49.1 hours) have been accomplished; but, schedules 5 and 6 have not yet been flown. These will be finished in the near future. All data have been processed from analog to digital form and they are being plotted and analysed. Theses, reports, and the design manual will be prepared and ready for publication in December.

A steering committee has been established to provide a working interface between potential industry users and the University research team. Industry members are from each of the following companies; Avco-Lycoming, Teledyne-Continental, Beech Aircraft, Cessna Aircraft, and Piper Aircraft. Formal meetings are scheduled twice each year at the University and frequent visits are planned at the individual company facilities. The purpose is to establish a mechanism for the exchange of ideas between the research group and the industry design group to insure the validity of program objectives and increase the probability of useful results and the direct transfer of technology developments to application.

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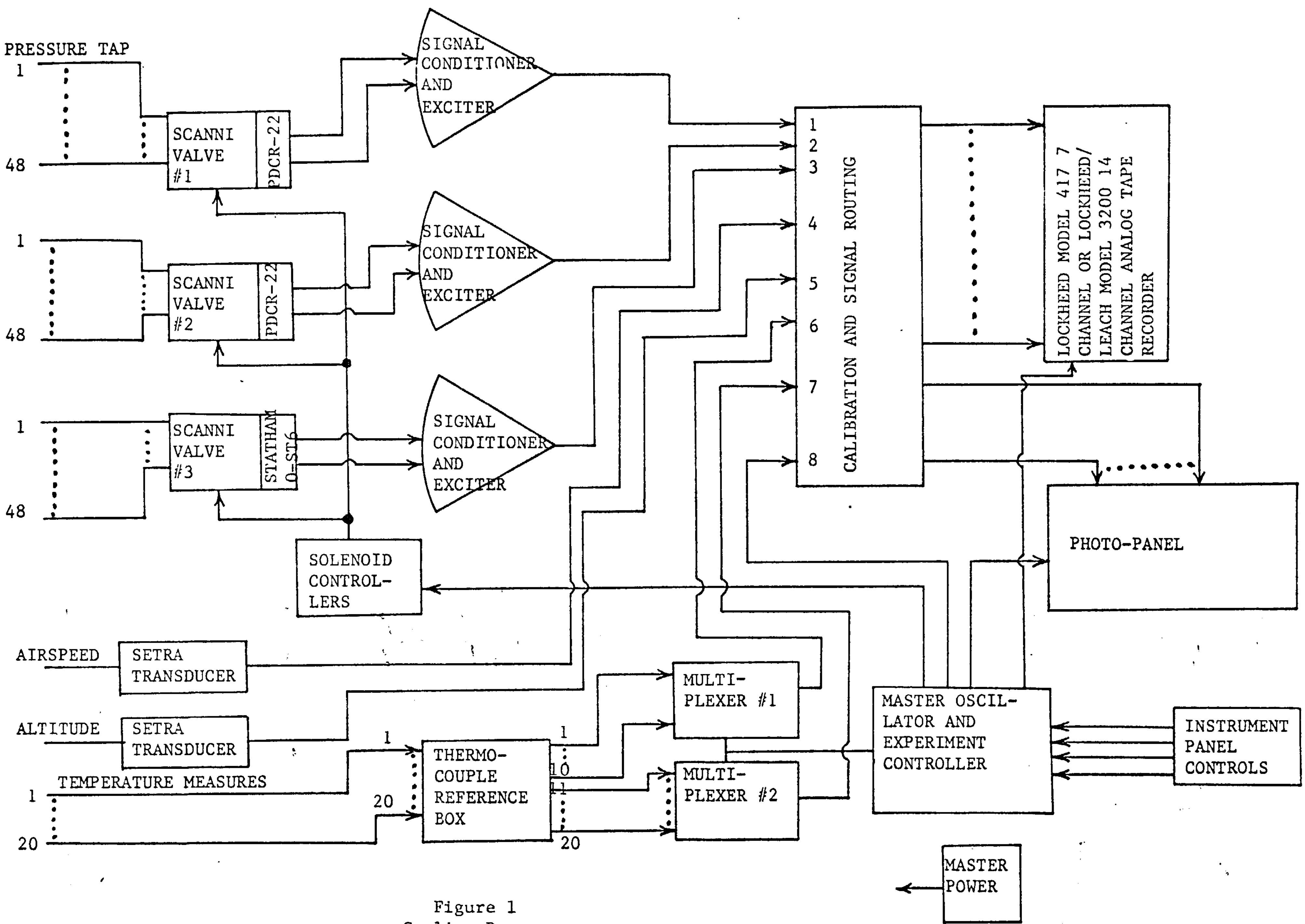


Figure 1
Cooling Drag
Instrumentation System

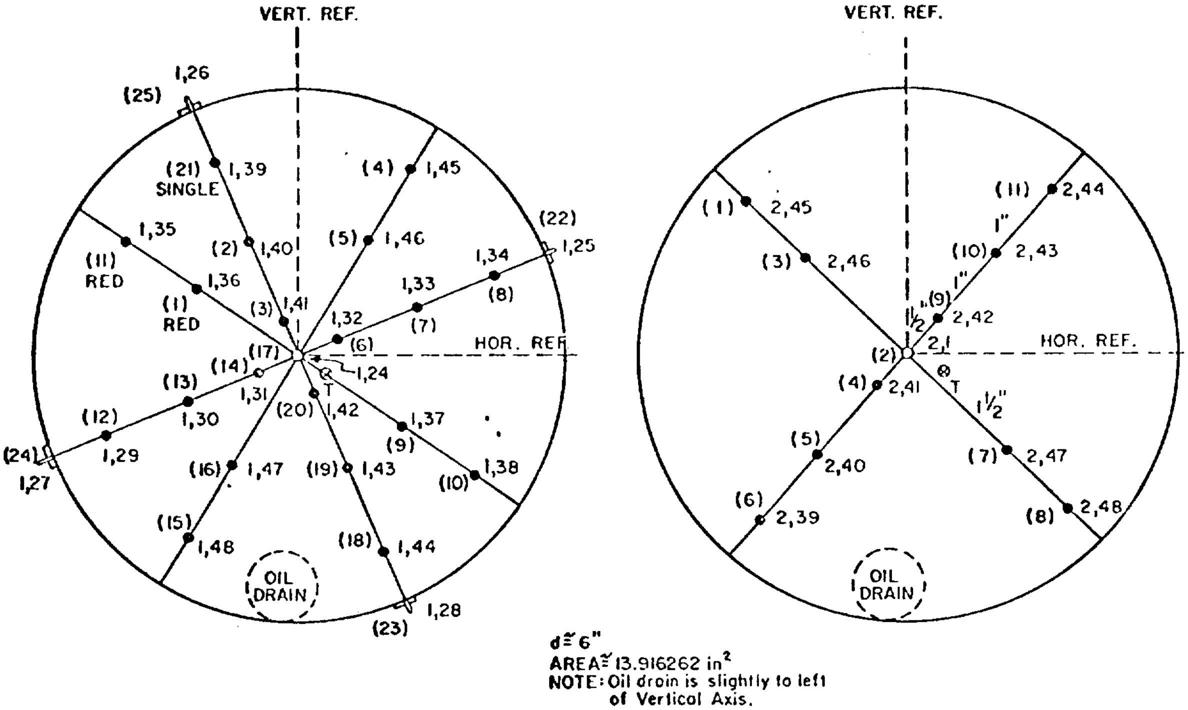
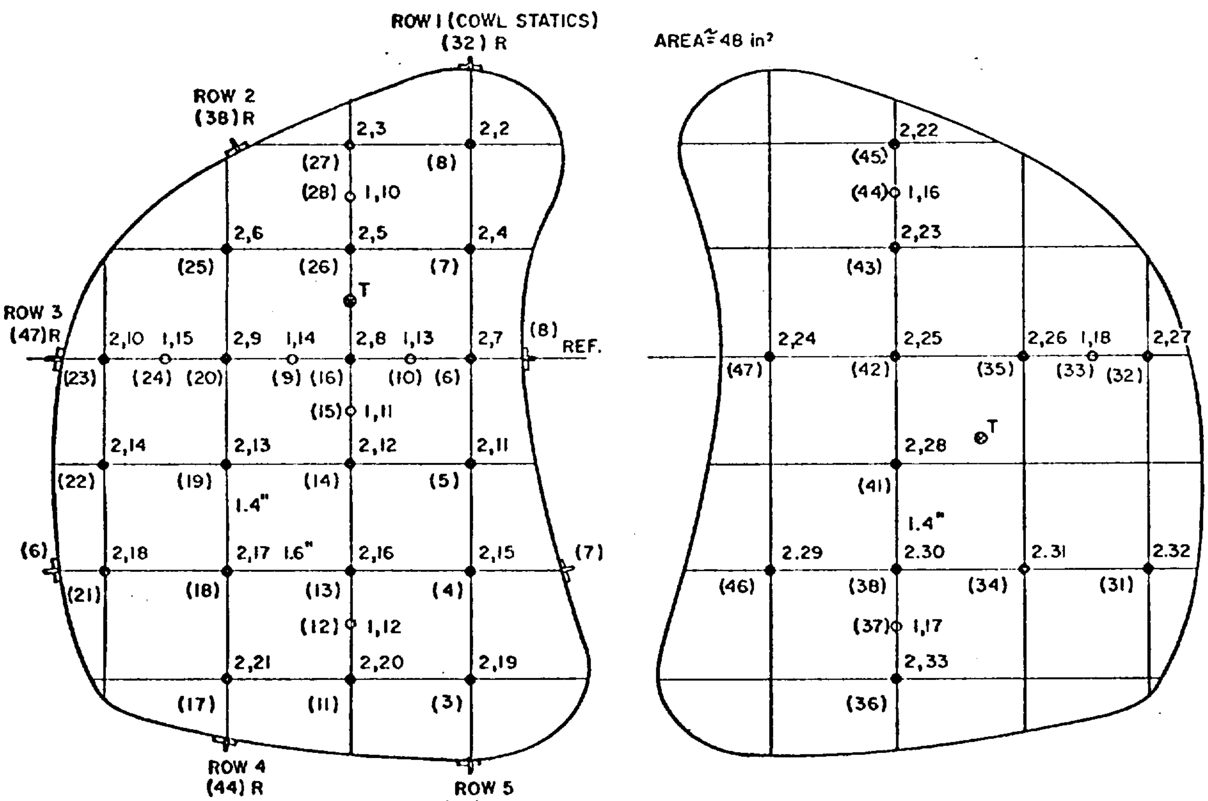


Figure 3. T-34 AUGMENTOR OUTLET (RIGHT)

T-34 AUGMENTOR OUTLET (LEFT)



INLET RAKE (LEFT)

Figure 2. INLET RAKE (RIGHT)

- ● TOTAL PRESSURE PROBE
- ○ STATIC PRESSURE PROBE
- ⊗ THERMOCOUPLE

1, 2, ..., 10	Total tube, located located above intercylinder baffles
11, 12, 13, 14	Static tube located below intercylinder baffles

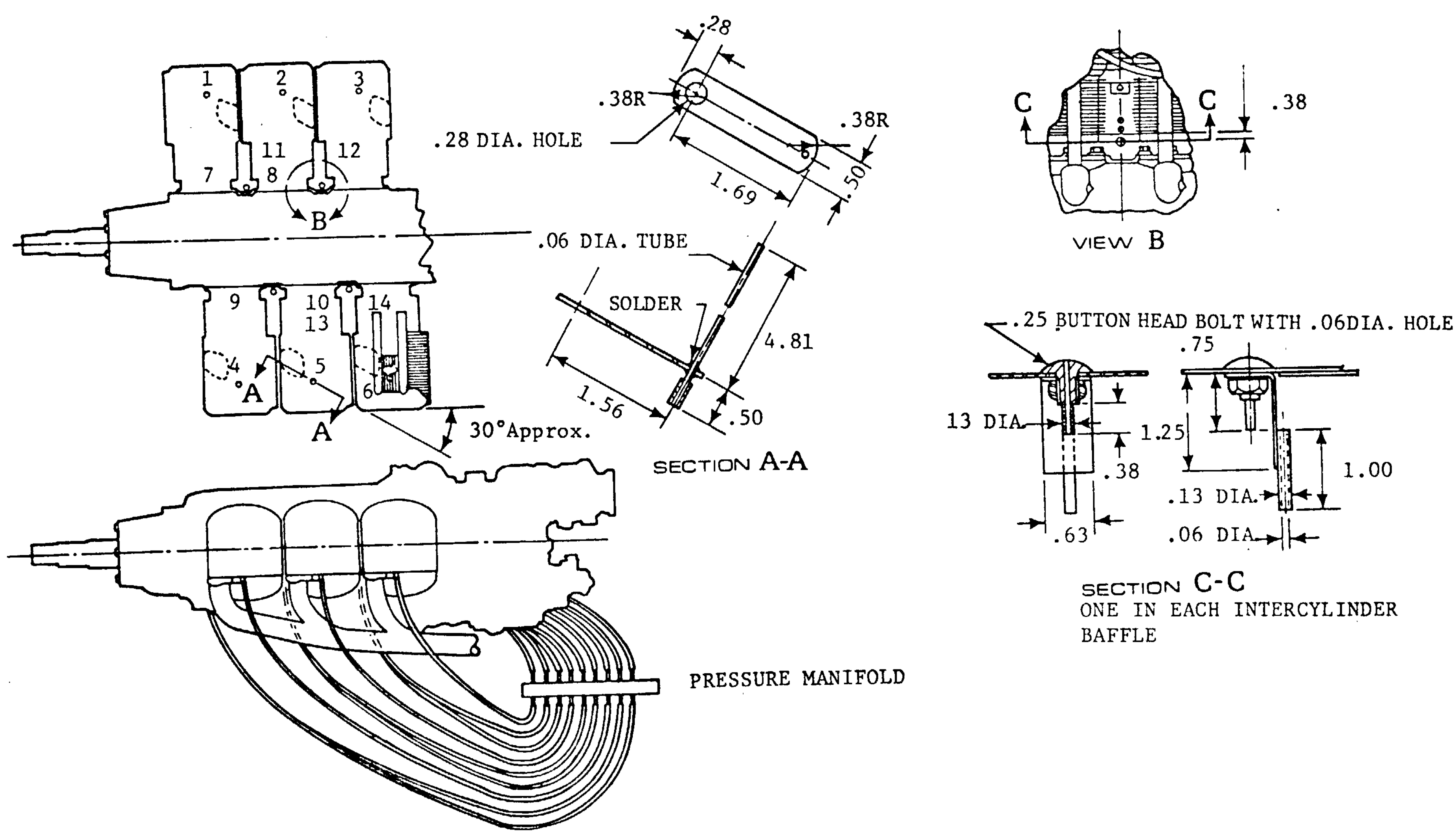


Figure 4. Engine Baffle Pressure-Probe Arrangement
(ref. Lycoming Aircraft Engine Installation Manual)

Table 1. Resume of Flight Test Program

IAS KNOTS	Schedule 1			Schedule 2	Schedule 3				Schedule 4		Schedule 5		Schedule 6	
	Pitot-Static Calib.			Drag Polar	Drag Polars - Augmentor Throttle								Engine Power	
	Bomb	Cone	Speed Course	Clean Conf.	25%	50%	75%	100%	#1 Drogue	#2 Drogue	Cowl	Closed	Climb	Cruise
70	O	O	O	O	O	O	O	O	O	O				
75	O	O	O	O	O	O	O	O	O	O				
80	O	O	O	O	O	O	O	O	O	O				
85	O	O	O	O	O	O	O	O	O	O				
90	O	O	O	O	O	O	O	O	O	O				
95	O	O	O	O	O	O	O	O	O	O				
100	O	O	O	O	O	O	O	O	O	O				
105	O	O	O	O	O	O	O	O	O	O				
110		O	O	O	O	O	O	O	O	O				
115		O	O	O	O	O	O	O	O	O				
120		O	O	O	O	O	O	O	O	O				
130		O	O	O	O	O	O	O	O	O				
140		O	O	O	O	O	O	O	O	O				
150		O	O	O	O	O	O	O	O	O				

Schedule Listing

1. Calibration Pitot Static System
2. Gliding Flight - Cowl Open
3. Gliding Flight - Augmentor tube throttle valve
4. Calibration Primary Instrumentation System
5. Gliding Flight - Cowl Closed
6. Power Flight - Cowl Open